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Accelerometer based performance assessment of basic routines in classical ballet

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Abstract

Classical ballet requires dancers to exercise significant muscle control and strength both while stationary and when moving. Following the Royal Academy of Dance (RAD) syllabus, 8 male and 27 female dancers (aged 20.2 $\pm$ 1.9 yr) in a full-time university undergraduate dance training program were asked to stand in first position for 10 seconds and then perform 10 repeats of a demi-plié exercise to a counted rhythm. Accelerometer records from the wrist, sacrum, knee and ankle were compared with the numerical scores from a professional dance instructor. The sacrum mounted sensor detected lateral tilts of the torso in dances with lower scores (Spearman's rank correlation coefficient r = -0.64, p < 0.005). The RMS acceleration amplitude of wrist mounted sensor was linearly correlated to the movement scores (Spearman's rank correlation coefficient r = 0.63, p < 0.005). The application of sacrum and wrist mounted sensors for biofeedback during dance training is a realistic, low cost option.

Keywords: accelerometer; classical dance; demi-plié; first position; sway;

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1. Movement in classical dance

Classical ballet requires dancers to demonstrate fluidity of movement, apparently effortless transition between movements and places/spaces, as well as the ability to balance and hold positions (both on flat feet, demi-pointe or pointe for females). Detailed instructions are available to dancers through various mental images of how to stand and move: Franklin (1996). Ballet dancers commonly use weight and fitness training to maintain strength and endurance, in addition to many hours per week in rehearsals: Angioli et al. (2009).

Children are introduced to dance at a very early age (commonly less than 3 years) and classical dance schools follow a well-documented and internationally accepted set of exercises. For example, the RAD in the United Kingdom has prescribed routines and examination requirements for dancers through the preliminary grades of 1-8 through to the advanced grades 1 and 2 of RAD level 4 certificates in Vocational Graded Examination in Dance (RAD Examinations Board, 2013). Other nations, including Australia, have similar requirements and examination procedures.

Whilst the complexity of movement and the artistic merit of a dancer progresses with the increased levels of proficiency, the basic movements learned and practised in RAD Grade 1 remain essential elements of the initial components of a ballet class, which is used both within a training context and as a warm up routine before dance rehearsals and performance.

In a typical rehearsal studio, dancers practice in front of a mirrored wall. This allows for the self-assessment of movement, aesthetic lines and a method of immediate feedback relating to the timing and appearance of such movements. However, the reliance upon mirrors has some disadvantages. The performance of dance repertoire in a theatre does not include the use of mirrors re: the provision of this feedback, and the dancers must be capable of maintaining their timing and aesthetic lines using only the music, their internal level of proprioception, and the movement of other dancers on stage at the time. The use of mirrors within a mirrored studio is not always ideal as dancers will be tempted to face the mirror or periodically glance at it which alters the position of their head and flow-on effects to other parts of their body. However, this distraction will not be evident during a performance on a stage.

There is some advantage in using other means of assessing movement and providing feedback to dancers and their instructors. The technology must be convenient to use, wireless, and capable of providing feedback quickly. If sensors are to be placed on the body, they must be small, light-weight and should not restrict movement.

A previous instrumented study of classical dance involved electromyographic analysis of leg muscles together with 2D video: Trepman et al. (1994). Eight muscles were selected on the right side of the body. The objective of the study was to assess muscle action during standing in first position and during demi-pliés and to contrast different patterns of muscle use between dancers with a classical training and modern dancers. Given the increasing use of small inertial units to monitor physical activity related to sport and healthy living, the use of such sensors in ballet is an obvious extension to these developments: Avci et al. (2010); James (2006).

The aim of the study was to determine if acceleration measurements are related to the scores from a professional dance instructor during preliminary dance exercises. The hypothesis was that acceleration measurements can be used to quantify performance during simple ballet activities: first position and demi-pliés. The null hypothesis becomes 'There is no relationship between ballet performance level and acceleration measurements during simple ballet activities'.

2. Research methods

Participants were recruited from the students in an undergraduate University dance training program. All students enrolled in the course must pass an audition in order to gain admission. Participation in this research was voluntary and all dancers signed a consent form as part of the Griffith University ethics approval requirement

(ENG/14/13/HREC).

Following an outline of the project aims, four inertial sensors were turned on and fitted to the right wrist (distal), right ankle (distal), immediately above the right knee (distal) and at the sacrum (medial) of each participant. The sensors were positioned using Velcro fabric bands. The locations of the sensors are illustrated in Figure 1. The inertial sensors were three axis accelerometers (size 75 mm x 28 mm x 8 mm, weight < 50 grams) which logged each data channel at 100 samples per second. When a three axis accelerometer sensor is stationary, the three axes readings can be used to measure the orientation with respect to the gravitational vector. The RMS value of the acceleration is a measure of the total acceleration including the effect of gravity. When the sensor is stationary, the RMS value of the acceleration is equal to g.

Eight male and 27 female dancers (age range 18 – 28 y) participated in the trials. All participants were weighed and their height measured. They self-reported age, dance experience in years, current training load and dance experience in various dance performance styles. All dancers reported weekly training of 38 $\pm$ 3.8 hours per week. The dancers had warmed up before any testing or measurements were undertaken. The dancers were scored out of a maximum of 10 points on their posture in first position and their movement performing demi-pliés.

The participants were asked to stand in classical ballet's first position (heels together with lower extremities laterally rotated) for ten seconds. The assessment of posture undertaken during this time was based on the alignment of the limbs and the position of the head and spine. Common problems include the incorrect arm position and a non-vertical spine.

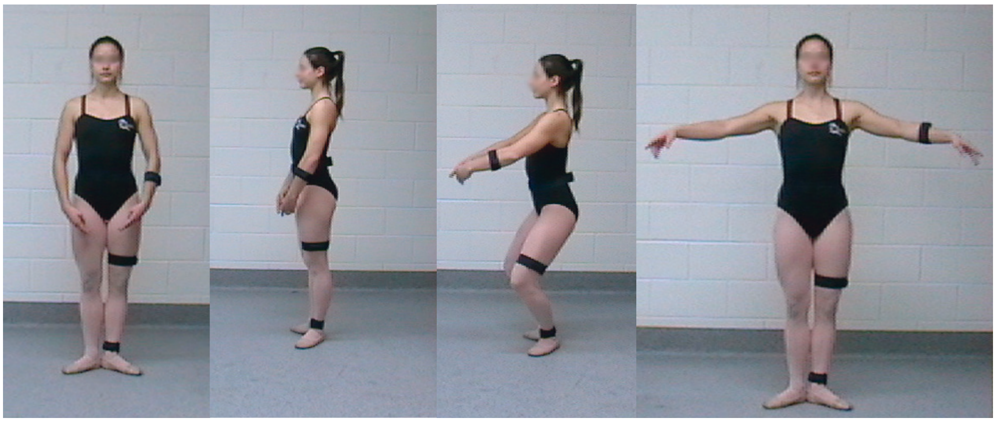

Fig. 1. The accelerometer sensor positions on the ankle, knee, wrist, and sacrum (obscured). The two right side images show the first position. The two left side images show frames during the demi pliés.

The dancers were then asked to perform a series of 10 demi-pliés timed with verbal counting. This consisted of three demi-pliés combined with a basic port de bras exercise – transitioning through the exercise required the dancer to lower their torso in space (i.e. height) by bending the knees whilst maintaining an upright torso and head, and then return to the beginning classical first position. Simultaneously the forearms are moved from the first position to a horizontal position in front of the body (i.e. preparation breath), to first position, out to second position and down again to the starting position of bras-bas. The position of the feet does not change (i.e. staying in first position). The assessment of this movement is based on the angle of the knees and alignment with the feet, the orientation of the spine and head, and the smoothness and timing of the movements. Common problems relate to a forward torso sway during the lowering phase and a backward torso sway during the rising phase.

A qualified dance instructor scored each dancer using a scale of 1-10 for the stationary position and the demi-plié exercise (movement routine) separately. This process followed the RAD examination requirements. Three dancers were recorded simultaneously using the four inertial sensors and a single video camera positioned 6 m from the line of dancers. The mirror in the dance studio was covered and the dancers faced the camera.

The accelerometer data and the video segments for each dancer were transferred to computer after the trials were complete. The accelerometer data was calibrated for each sensor unit individually and results presented in terms of the gravitational acceleration g = 9.8 ms^{-2}. The posture acceleration was determined from the mean values of each static acceleration component. The movement acceleration was determined by subtracting the maximum acceleration from the minimum acceleration measurement in one complete movement cycle. The video record was used to review the test procedure.

3. Results

The posture and movement scored results (Table 1) show a slightly higher average score for the female dancers.

Table 1. Posture and movement scores (median and range) for male and female dancers. The mean and standard deviations for the age, height and weight are included.

	Age (years)	Height (cm)	Weight (kg)	Posture Score	Movement Score
Males (n=8)	20.9 ± 3.2	173.9 ± 5.8	68.9 ± 9.9	6.5 (2-9)	5.5 (3-9)
Females (n=27)	20.0 ± 1.4	163.1 ± 4.8	55.4 ± 4.7	7 (4-9)	7 (3-10)

3.1. First position

The accelerometer records show near vertical orientation (measured with respect to the direction of gravity) for all dancers for the ankle (males: $a = 0.97 \pm 0.04$ g, females: $a = 0.99 \pm 0.015$ g), knee (males: $a = 0.98 \pm 0.2$ g, females: $a = 0.98 \pm 0.01$ g), sacrum (males: $a = 0.98 \pm 0.03$ g, females: $a = 0.99 \pm 0.01$ g) and wrist (males: $a = 0.90 \pm 0.07$ g, females: $a = 0.94 \pm 0.04$ g). The horizontal axes at all sensor positions are the most sensitive measures of orientation as the relationship between the static acceleration and the angle measured from the vertical is sinusoidal.

The sensor on the sacrum showed deviations from the horizontal axes. The maximum value was 4.0 degrees ($a = 0.07$ g) for the sacrum lateral axis and 25 degrees ($a = 0.49$ g) along the sacrum coronal axis. These variations did not correlate with the posture scores (Spearman's rank correlation coefficient $r = -0.04$ and -0.004 respectively). The sensor tilt is a measure of the accuracy in positioning the sensor using the waist band as well as the orientation of the hips and spine at the lower back.

The wrist mounted sensor indicated that dancers with the higher scores had smaller deviation from vertical however the trend was only weakly correlated (Spearman's rank correlation coefficient $r = 0.4$: $p = 0.02$).

3.2. Demi pliés

The accelerometer records for the ankle, knee, sacrum and wrist showed a characteristic rhythmic pattern in most axes (Figure 2 shows the acceleration profiles from two different dancers). The ankle and knee movements are complementary. There is no obvious difference between the two plots as the amplitude and general shape of the accelerometer profiles are similar. These measurements can not distinguish between these two dancers (scored 4/10 and 7/10). The high frequency jitter on the accelerometer records occurs at the same time in each cycle but at different times for different sensor locations and different dancers. The jitter is thought to result from high speed muscle activity which is directly related to joint stability. These high frequency waveforms are not identical between cycles because the sensor sampling speed is too slow to capture more than one data point during the high frequency cycle (approximately 50Hz). This is consistent with the frequency ranges observed in EMG recordings of muscle activity where RMS values of EMG output were recorded: Trepman et al, (1996).

The wrist acceleration showed the largest amplitude with the axial acceleration (i.e. in the direction of the forearm) reaching values of greater than 1 g for all participants. This amplitude is the result of both the change in the forearm orientation with respect to gravity and the angular velocity derived centrifugal acceleration associated with a combination of both the elbow and the shoulder pivot points. The root mean square value (RMS) of three acceleration amplitudes were calculated and plotted as a function of the movement score. The relationship showed a moderate dependence (Spearman's rank correlation coefficient r = 0.63: p = 0.02: females only r = 0.56: p = 0.026, males only r = 0.82: p < 0.005).

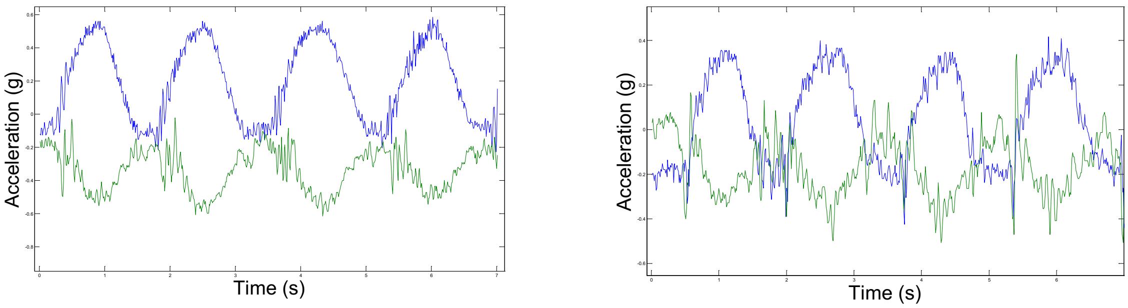

Fig. 2. The accelerometer sensor outputs for four demi-pliés. The upper trace is the ankle axial acceleration and the lower trace is the knee axial acceleration. Participant 12 (left figure) was scored 4/10 and the participant 28 (right figure) was scored 7/10. The same accelerometer unit was used for both measurements.

Dancers with a movement score in the range 8-10 showed no detectable sagittal variation at the sacrum (angle < 2.5 degrees) during demi-pliés. All other dancers (scored 4-7) showed variations greater than 2.5 degrees. The Spearman rank correlation coefficient for sagittal variations on the sacrum was r = -0.65: p < 0.005 for all dancers (males: r = -0.59: p = 0.06, females: r = -0.64: p < 0.005).

The acceleration components measured above the knee and at the ankle showed little or no correlation with score. The Spearman rank correlation coefficient analyses resulted in p > 0.08 for all cases and for both male and female dancers. This suggests that most dancers lowered their torso at an acceptable level, and the manner of movement was differentiated by the dance instructor using different criteria.

4. Discussion and Conclusions

This study analyzed first position and one demi-plié routine performed by 35 students of dance. It was concluded that accelerometers placed on the sacrum and the wrist are the best indicators of skill level for the demi-plié. The sacrum provides accurate information about the posture of the dancers during 10 seconds at first position and during a series of demi-pliés. Those dancers that were scored highly in movement showed no observable change in their sagittal lateral plane. The variations observed are the result of the asymmetrical movement of the legs and body sway related to a smaller "turn out" of the feet (i.e. the angle between the feet in the horizontal plane is smaller than that found in elite dancers). The RMS movement of the wrist (based on the amplitude of the accelerometer changes) correlated with skill level. This can be attributed to the extension of the arms and so indirectly to the angular velocity of the movement. We conclude that the original hypothesis has been verified: acceleration measurements (in particular the wrist RMS and sacrum tilt) can be used to quantify performance during simple ballet activities: first position and demi-pliés ($p > 0.94$).

The sensors on the ankle and knee showed little relationship with assessed dance skill both in first position and during demi-pliés. All dancers in this study had some years of dancing experience – many had up to 16 years of experience and were involved in dance training for more than 40 hours per week immediately prior to testing. The use of knee and ankle sensors might be of value in assessing the progression of novice dancers. A preliminary examination of the high frequency characteristics of the accelerometer data showed little difference with this measure and the movement scores. This implies that joint stability and micro-level muscle control are not significant impediments to high quality dance. The low frequency data from the first position records does indicate some body sway. This is likely to be far more significant in determining core stability, postural sway and balance. As children develop, there are changes in postural sway in the frequency range from 0.05 Hz to 4 Hz: Riach and Hayes (1987). While the principal spectral components of swaying in adults lies in the range 0.05 to 0.7 Hz, with children the highest spectral components were found in the frequency range 0.8 to 2 Hz. As many children take dance classes from the age of three years, accelerometer sensors might be used to observe the frequency and magnitude of swaying as a required ballet skill.

As accelerometers are small, low cost and easily positioned on the body using comfortable fabric bands, a wireless connection to a computer screen should provide invaluable feedback to the dancer about their movements. Although artistic merit is scored in the RAD examinations, the accelerometer system can not provide this information, even with the two Grade 1 ballet exercises explored in this investigation. These observations provide opportunities for further research.

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